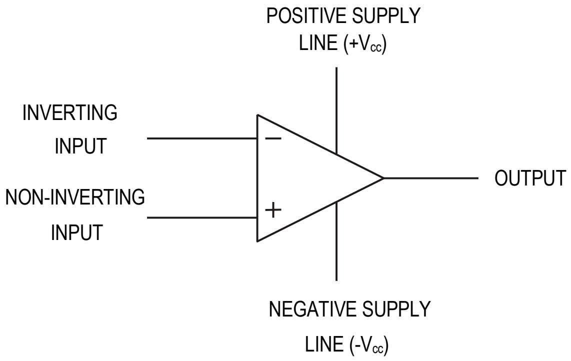
OPERATIONAL AMPLIFIERS

Circuits with specific designs can be constructed on a single piece of silicon chip. These are known as **i**ntegrated **c**ircuits.

One such ic is known as an operational amplifier **- op. amp**.

This ic was designed to perform mathematical operations.
The op. amp. can be used to add, subtract, multiply, divide, integrate and differentiate electrical voltages.
It can amplify both d.c. and a.c. signals.

The symbol for an op. amp. is shown below.



The op. amp. is designed to amplify the difference between the two input voltages.

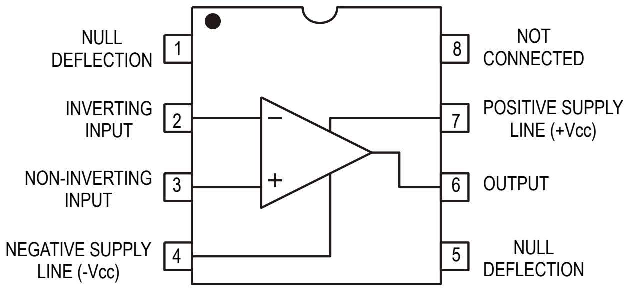
The two inputs are indicated by a "-" and "+".

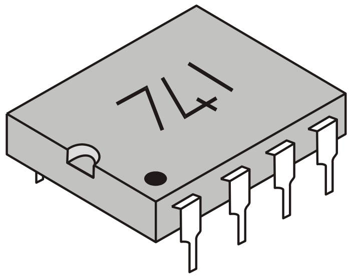
A positive signal to the "-" input is amplified and appears as a negative signal at the output. **– inverting input**

A positive signal to the "+" input is amplified and appears as a positive signal at the output. **– non inverting input**

If both inputs are exactly the same i.e. there is no difference, then the output should be zero.

It is normal practice to omit the power lines when drawing diagrams - these are taken for granted.





The top of any ic is usually indicated by a notch. Occasionally pin number 1 is indicated by a dot. Pins are always numbered from pin 1 in an anti - clockwise direction.

GAIN

The op. amp. was designed as a voltage amplifier.

The voltage gain of any amplifier is defined as

$$Voltage \quad gain = \frac{Voltage \quad output}{Voltage \quad input}$$

$$A_V = \frac{V_o}{V_i}$$

For a differential amplifier, the voltage input is the <u>difference</u> between the two inputs.

V_i = ($V_{\text{(at non - inverting input)}}$ - $V_{\text{(at inverting input)}}$)

ASSIGNMENT 2.01

a) If $V_{(\text{at non - inverting input})}$ = 3.10 V and $V_{(\text{at inverting input})}$ = 3.11 V. Calculate the input voltage and hence the output voltage if the gain is known to be 100.
b) The gain of an op. amp. is known to be 100,000. If the output voltage is 10 V, calculate the input voltage.

c) The gain of an op. amp. is known to be 200,000. If $V_{(\text{at non - inverting input})}$ = 2.5 V and $V_{(\text{at inverting input})}$ = 2.2 V, calculate the output voltage.

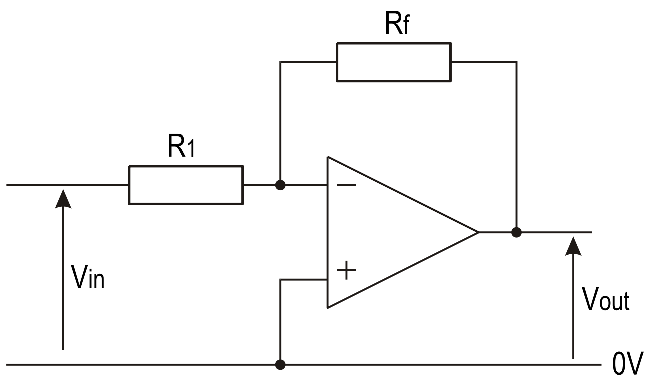
The answer to (c) is obviously unrealistic since the output voltage from an op. amp. cannot be greater than the supply voltage.

As the output of the op. amp. increases, saturation starts to occur and a "clipping" effect will be noticed. This normally occurs when the output reaches 85% of V_{CC}
Any further increase in the input will cause no further increase in the output since the op. amp. has reached saturation.

THE INVERTING AMPLIFIER CONFIGURATION

The signal is connected to the inverting input through an input resistor R_1.

The non - inverting input is connected to ground.



voltage gain, $A_v = -\frac{R_f}{R_1}$

WORKED EXAMPLE

A circuit configured as an inverting op amp with R_1 = 15 k and R_f = 470 k. Calculate the gain of the circuit and determine the output voltage when an input signal of 0.2 v is applied.

Step 1
Calculate the gain

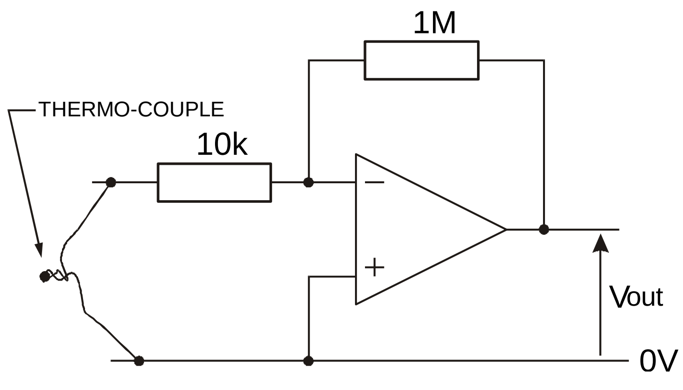
$$A_v = -\frac{R_f}{R_1} = -\frac{470k}{15k} = \underline{-31.33}$$

Step 2
Calculate the output voltage

V_{out} = A_v x V_{in} = - 31.33 x 0.2 = $\underline{-\ 6.266\ V}$

ASSIGNMENT 2.02

A thermocouple known to produce an output of 40 μ volts per °C is connected to an op. amp.



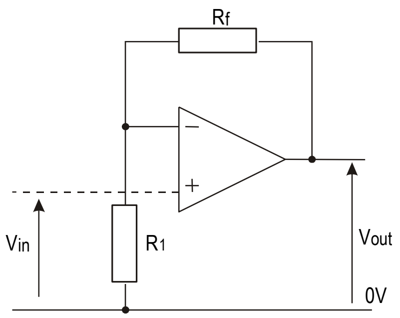
a) Calculate the gain of the circuit.

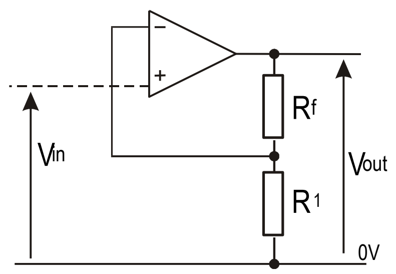
b) Determine the output voltage if the thermocouple is heated to a temperature of 1000 °C.

For an inverting amplifier, the sign of the output voltage is the opposite of the input voltage. In order to obtain the same sign, the output signal could then be fed through another inverter (with R_f = R_1, so that the gain = -1).

THE NON - INVERTING AMPLIFIER CONFIGURATION

The signal is connected directly to the non - inverting input.
R_f and R_1 form a voltage divider circuit feeding back some of the output signal to the inverting input.
The circuits below show two different ways of drawing the same circuit.

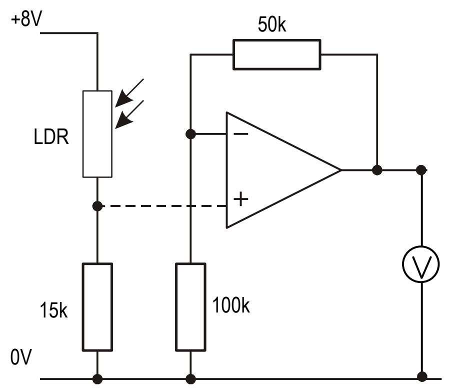




voltage gain, $A_V = 1 + \frac{R_f}{R_1}$

ASSIGNMENT 2.03

To build a simple light meter, a light dependent resistor (LDR) is connected into a circuit as shown below.



In bright sunlight, the LDR has a resistance of 1 k. In shade, it's resistance increases to 15 k.

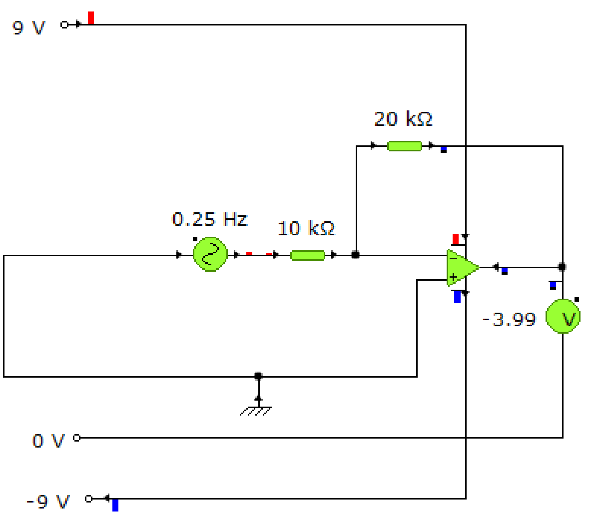
a) Determine the voltages that would appear on the voltmeter in both light conditions.
b) How could the circuit be altered to indicate changes in temperature?

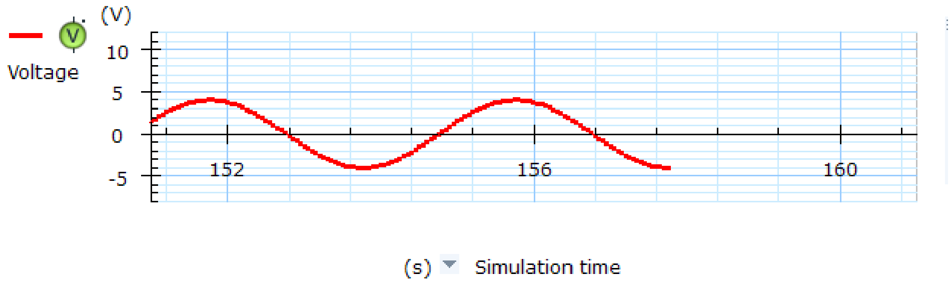
CIRCUIT SIMULATION SOFTWARE.

It is possible to use circuit simulation software such as Yenka to investigate electric and electronic circuits. Circuit simulation is widely used in industry as a means of investigating complex and costly circuits as well as basic circuits.

Circuit simulators make the modelling and testing of complex circuits very simple. The simulators make use of libraries of standard components along with common test equipment such as voltmeters, ammeters and oscilloscopes.

Construct the circuit shown below.





Set the input voltage to 2 Volts, 0.25 Hz.

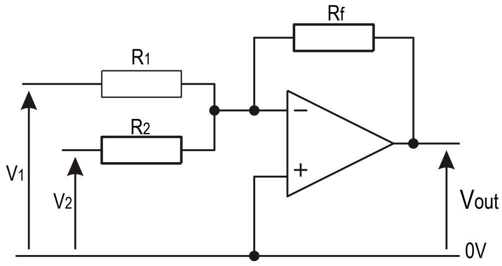
Set the oscilloscope to a maximum voltage of 10 V and a minimum voltage of -10 V

Start the trace on the oscilloscope and compare the input and output voltages.

Now increase the size of the feedback resistor to 50 k and repeat the exercise. This time you should observe "clipping" of the output signal.

THE SUMMING AMPLIFIER

Here, two (or more) signals are connected to the inverting input via their own resistors. The op. amp. effectively amplifies each input in isolation of the others and then sums the outputs.



Characteristics of the summing amplifier

Each input signal is amplified by the appropriate amount (see inverting mode)

$V_{out} = (-\frac{R_f}{R_1} \times V_1) + (-\frac{R_f}{R_2} \times V_2)$ + (any other inputs)

Notes:

- any number of inputs can be added in this way.
- R_f affects the gain of every input.

$V_{out} = (-\frac{R_f}{R_1} \times V_1) + (-\frac{R_f}{R_2} \times V_2)$ + (any other inputs)

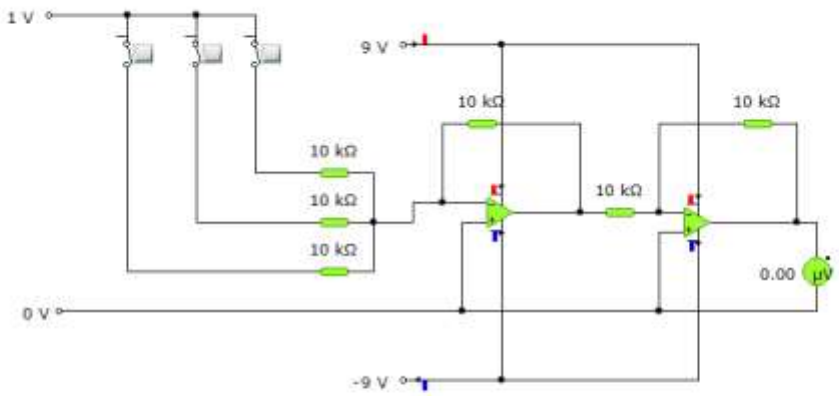
$$V_{out} = -R_f (\frac{V_1}{R_1} + \frac{V_2}{R_2} + ...)$$

CIRCUIT SIMULATION

1. Digital-to-analogue converter

Digital devices produce ON/OFF signals.

This circuit contains a summing amplifier and an inverting amplifier.



Since all inputs are amplified by the same amount (same value of input resistors) the output voltage = $\sum$ input voltages e.g. S1, ON (connected to 1V) and S2, ON (connected to 1V) , the output voltage should = (1 + 1) = 2V

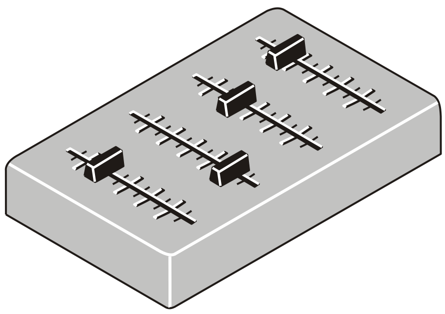
Now change the circuit so that R_2 = 5k and R_3 = 2.5k

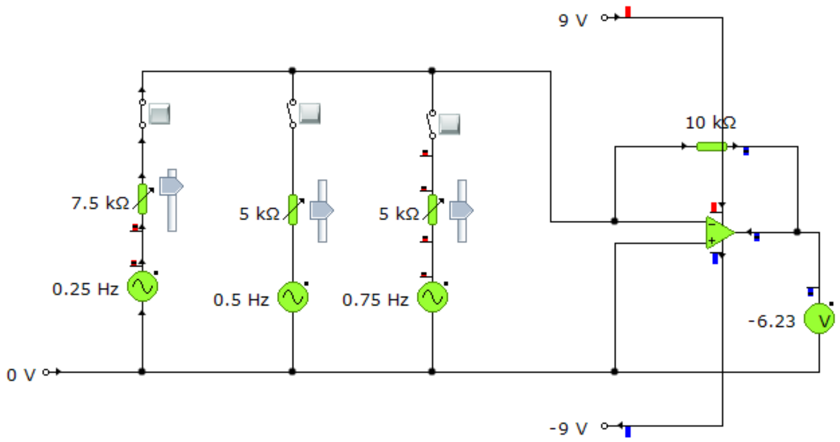
Copy and complete the following table to show the state of the input switches and the output voltage.

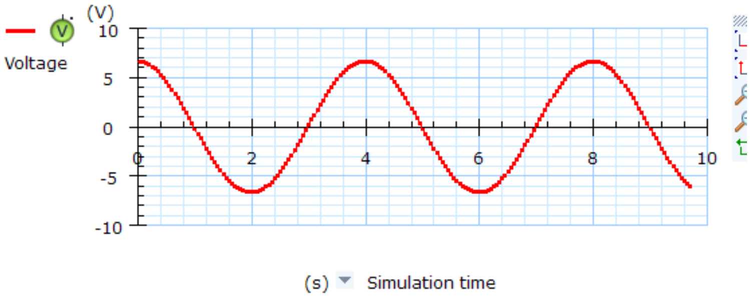
S3	S2	S1	output voltage (V)
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

2. a.c. mixer pre-amplifier

Mixers allow different signals to be amplified by different amounts before being fed to the main amplifier. Signals might come from microphones, guitar pick-ups, vocals, pre-recorded sound tracks etc.







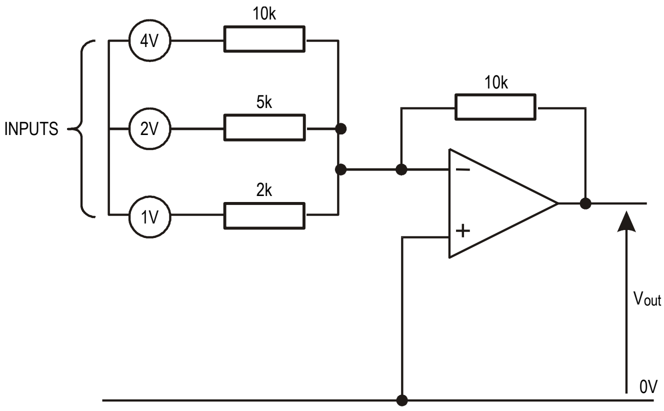
Putting each switch on individually will allow you to “see” each of the input signals in turn.

Putting more than one switch on at a time will show you the sum of the input signals.
Adjusting the size of the input variable resistors alters the amplification of that particular input signal.

Complex output signals can be constructed by adding sine waves of the correct amplitude and frequency - useful in electronic keyboards or synthesisers when a particular musical instrument is required.

ASSIGNMENT 2.04

Determine the output voltage for the circuit shown below.

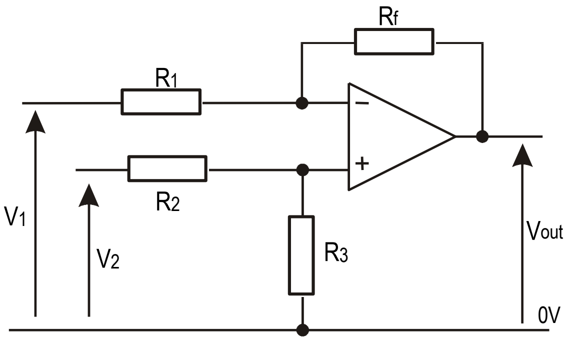


ASSIGNMENT 2.05

A personal stereo has both tape and radio inputs which produce output signals of 50 mV and 10 mV respectively. The amplifying system consists of a main amplifier and uses an op. amp. as a pre - amplifier. Design a possible pre - amplifier circuit so that an output of 1 volt is produced when either the tape or radio inputs are used.

THE DIFFERENCE AMPLIFIER CONFIGURATION

Here both inputs are used.
The op. amp. amplifies the difference between the two input signals.



To ensure that each input is amplified by the same amount, the circuit is designed so that the ratio:

$$\frac{R_f}{R_1} = \frac{R_3}{R_2}$$

To ensure that the input resistance of the circuit for each input is the same,

$$R_1 = R_2 + R_3$$

Characteristics of the difference amplifier

$$A_V = \frac{R_f}{R_1}$$

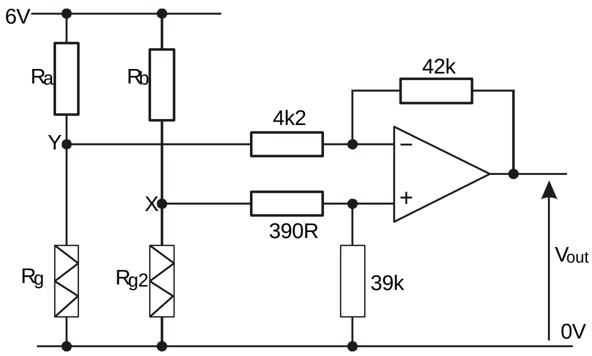
$$V_{out} = \frac{R_f}{R_1} \times (V_2 - V_1)$$

If $R_1 = R_f$ then $A_V = 1$ and $V_{out} = (V_2 - V_1)$, the circuit works as a "subtracter". the output will be zero if both inputs are the same.

This circuit is used when comparing the difference between two input signals.

ASSIGNMENT 2.06

Two strain gauges are connected to a difference amplifier as shown below.



$R_A = R_B = 1$ k, when not under strain, $R_{g1} = R_{g2} = 200\ \Omega$

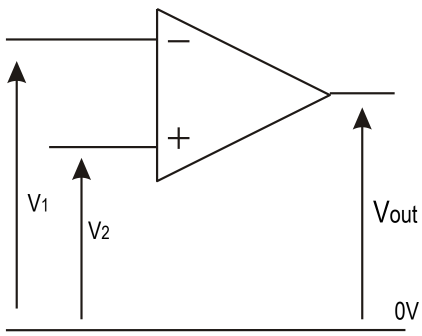
a) Calculate the voltage at X and Y when both gauges are not under strain and hence determine the output voltage of the amplifier.

b) As the strain of R_{g2} increases, its resistance increases from 200 to 210 Ω, determine the new output voltage.

c) What would you expect to happen to the output voltage if both gauges were put under the same amount of strain?

THE COMPARATOR CONFIGURATION

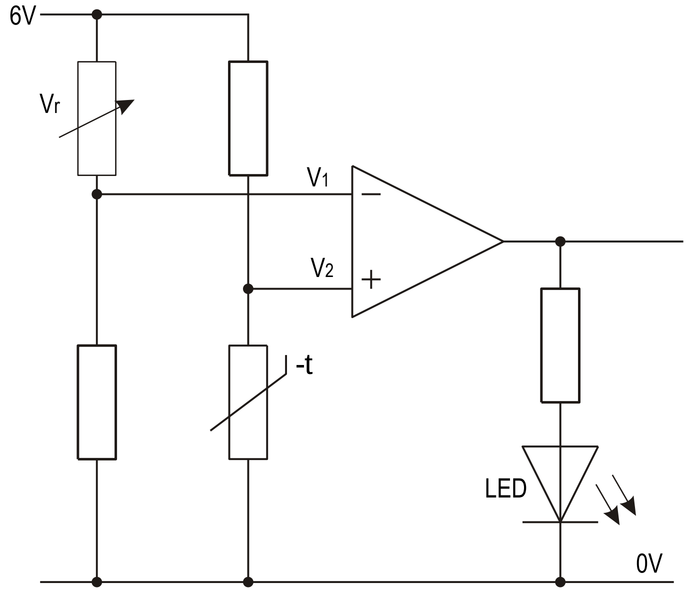
This is a special case of the difference amplifier in which there is no feedback. Any small difference in the two input signals is amplified to such an extent that the op. amp. saturates either positively or negatively.



if $V_2 > V_1$, V_{out} is **positive**, if $V_2 < V_1$, V_{out} is **negative**

This is commonly used in control circuits in which loads are merely switched on and off.

The circuit shown below would give an indication when the temperature falls below a preset value, 0°C for example.



V_r is adjusted until V_1 is just greater than V_2, the output will therefore be negative and the led will be off.

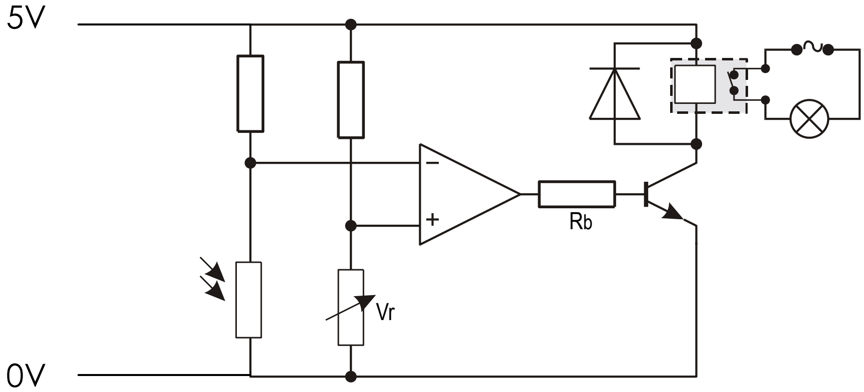
As the temperature falls, the resistance of the thermistor rises and therefore V_2 starts to rise. Eventually, $V_2 > V_1$, the output goes positive and the led lights.

DRIVING EXTERNAL LOADS

The maximum output current that can be drawn from an op. amp. is usually low (typically 5 mA). If larger currents are required, the output could be connected to a transducer driver either a bipolar transistor or MOSFET and relay circuit if required.

ASSIGNMENT 2.07

Describe the operation of the circuit shown and state the purpose of the variable resistor V_r and the fixed resistor R_b



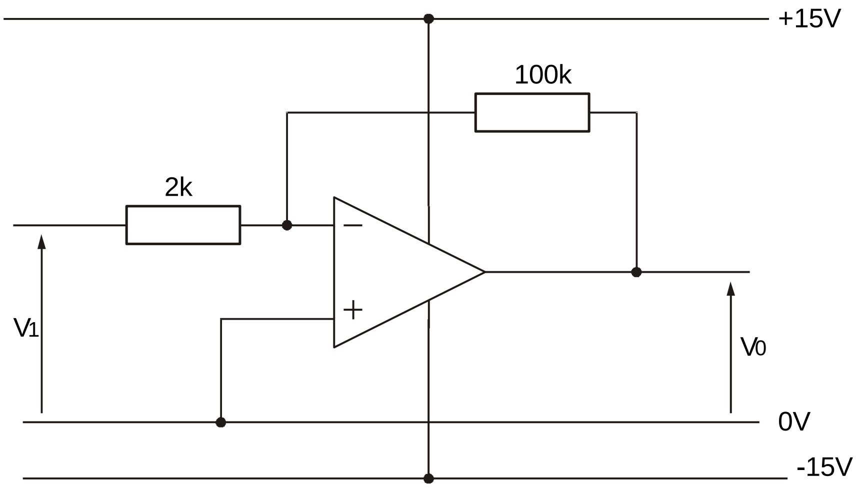
ASSIGNMENT 2.08

(a) Name the configuration of the amplifier shown below.

(b) Calculate the gain of the amplifier.

(c) (i) If the input signal V_i is 0.5 V, what is the value of the output signal V_o?

(ii) **Explain** your answer.



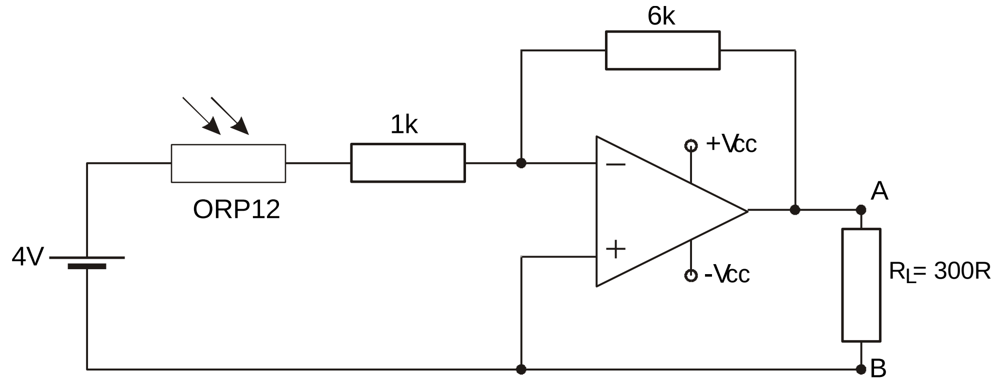
ASSIGNMENT 2.09

The op amp circuit below includes an ORP12 light dependent resistor as an input sensor.
When the light level on the LDR is 50 lux, determine:

(a) the resistance of the LDR;

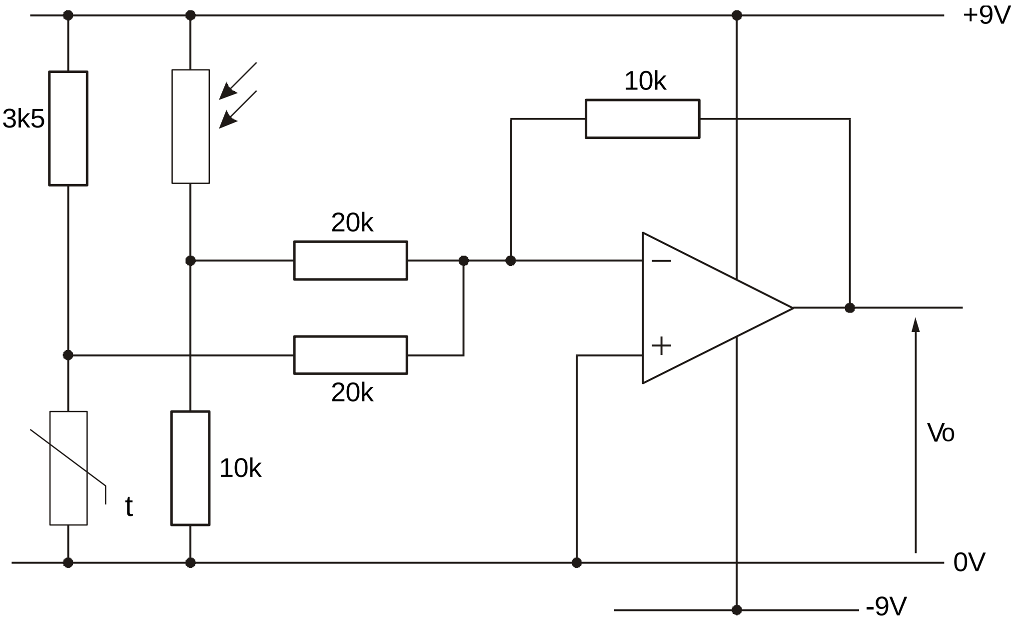
(b) the voltage gain of the operational amplifier;

(c) the current flowing through the load resistor R_L, stating clearly the direction in which it is flowing.



ASSIGNMENT 2.1

A technological experiment involves recording the total effects of light and temperature. It utilises an operational amplifier configured as shown below.



(a) Name the configuration of the amplifier used in the experiment.

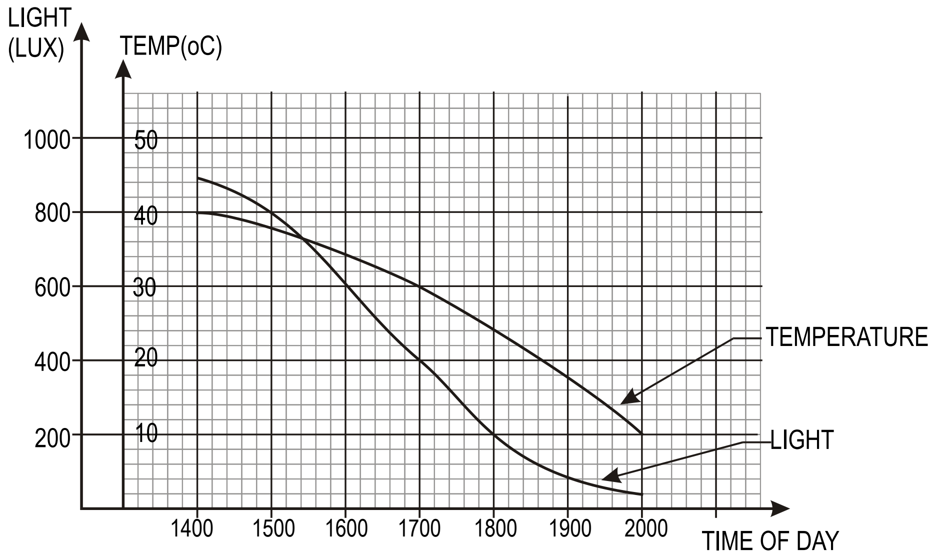
(b) Explain clearly how the system operates.

(c) Determine the gain of the amplifier.

(d) Comment on the suitability of the value of the gain in this particular circuit.

The following graph shows the actual temperature and light readings recorded during the experiment between the hours of 1400 and 2000 on one particular day.

The characteristics of the light dependent resistor and a type 3 thermistor used in the circuit are shown.



(e) Determine the output voltage (V_o) from the circuit at 1700 hours.

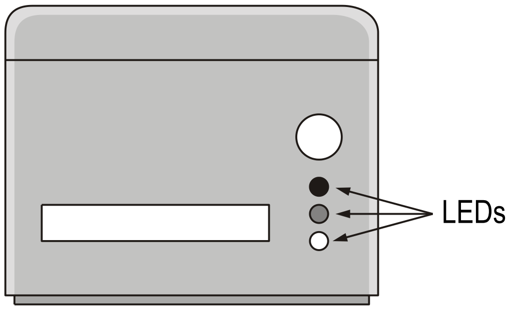
(f) For later processing, this value of (V_o) must be positive.

(i) Name an additional device which can be added to the circuit to produce a positive value for V_o.

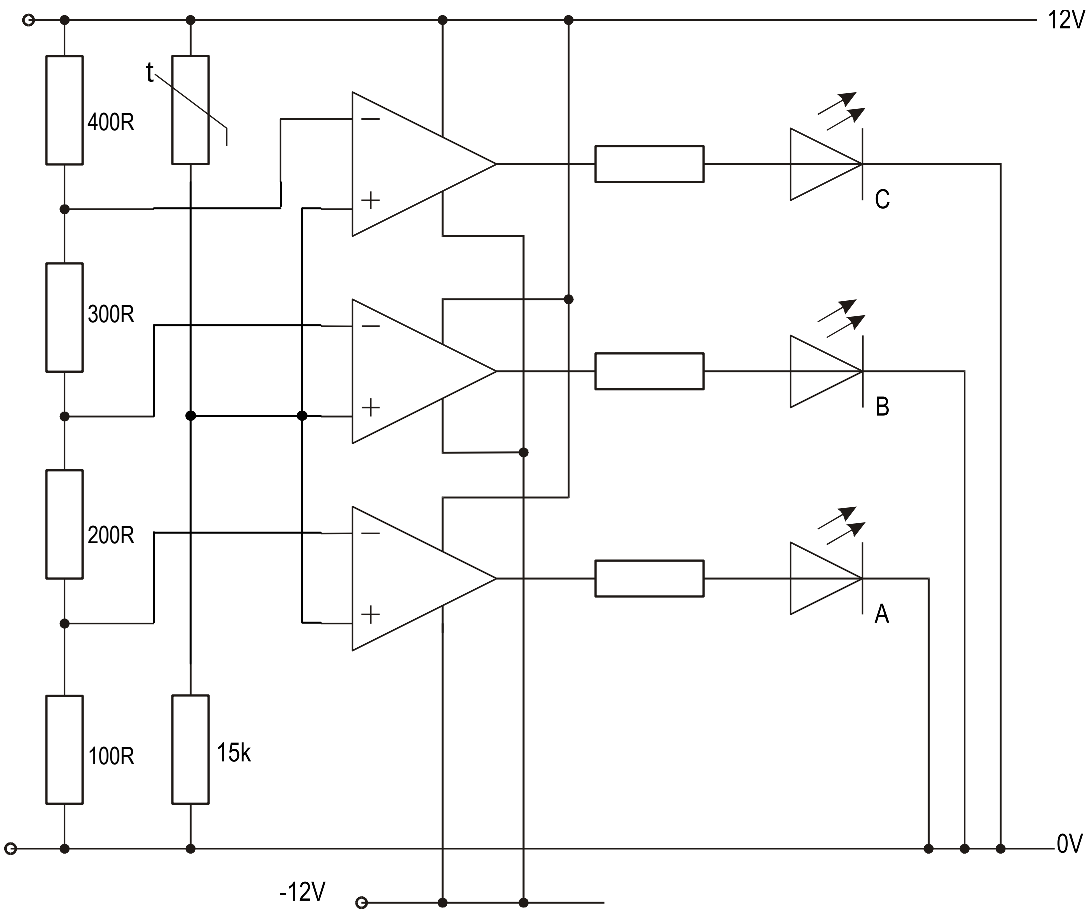
(ii) Draw the circuit for this additional device and indicate the value of any components used.

ASSIGNMENT 2.11

A deep-fat fryer incorporates a cooking oil temperature indicator. An array of LEDs is shown on the control panel and, as the temperature of the cooking oil increases, the LEDs light in a ladder sequence.



The circuit shown is used to control the lighting of the LEDs. The circuit utilises three 741 operational amplifier IC's and a type 6 thermistor.



(a) In which amplifier mode are the 741 Ics being used ?

(b) Explain in detail why the LEDs light up in sequence as the temperature of the oil increases. The function of the components in the circuit should be included in your explanation.

(c) At what temperature will LED “C” light ?

(d) If the current through each LED is to be limited to 200 mA, determine what value of resistor should be connected in series with each LED.

ASSIGNMENT 2.12

A camera manufacturer is evaluating a design for a light level indicator, details of which are shown in the circuit below.

Determine the **range** of values of the input voltage V_{in} over which the LED will glow to indicate that a photograph may be taken.